STUDIES ON GAS PRODUCTION AND RETENTION

IN WHEAT FLOUR DOUGHS

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University of Alberta

April, 1932.

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TABLE OF CONTENTS

Table of Contents (Continued-) Page

TABLE OF FIGURES

# STUDIES ON GAS PRODUCTION AND RETENTION IN WHEAT FLOUR DOUGHS

by

Robert Grenville Dunlop

## INTRODUCTION.

The ability of a flour to produce a large well-piled loaf of low density depends first, on the production of gas within the fermenting dough, and second, on the retention of a large proportion of this gas within the dough. The production of the gas is accomplished primarily by the diastatic enzymes which are present in the flour and by the yeast enzymes which are added to it. The retentive capacity of the dough, on the other hand, is a function of the quantity and quality of the gluten proteins. Either or both of these two factors, gas production and retention, may be modified by the processes and formulae of the baker, but the quality of a flour is primarily dependent on its natural efficiency in these two respects. In this research the properties of four flours of different baking quality have been investigated with respect to their gas production and retention, and the effect of various processes and formulae on these properties.

## LITERATURE REVIEW

A flour of good baking quality must contain a sufficient quantity of protein to prevent shortness in the dough and give structural strength to the loaf. The importance of this quantity factor has been well illustrated by Johnson and Bailey (11) and by Hopkins (8) in their investigations of the importance of a high protein-starch ratio in flours. They lowered the ratio by the simple expedient of adding starch to the flours and tested their results by baking. The properties of the doughs were considerably impaired and smaller loaves were produced. The importance of a high protein-starch ratio was thus demonstrated.

The quality of the protein, however, is possibly of even greater importance. The gluten network must be of a tough elastic nature, so that it will expand evenly under the influence of the gas produced, and give a loaf of close texture. Any deficiency in this respect will result in a poorly shaped loaf containing large air holes.

It was thought formerly that the quality of the protein depended upon its chemical constitution. This hypothesis became untenable when it was shown that the proteins of both strong and weak flours were chemically identical (5,19). Gröh and Friedl (7) and more recently, Woodman (20) in extensive physico-chemical studies on the protein of strong and weak flours, have found the gliadin in each sample to be identical in physical properties. Quality is now explained on the basis of the colloidal and other physical properties of the flour and by the effect of various constituents of the flour on these properties. The study of this phase of baking strength has accordingly become much more complex.

These theories of quality are covered by the various definitions of strength, couched in terms of gas production and retention, which have recently appeared in the literature (1,2,13,19). The most comprehensive is probably that of Bailey (1), who defines strength as "determined by the ratio between (a) the rate of production in, and (b) the rate of loss of carbon dioxide from the fermenting mass of dough." This was qualified, however, by taking into consideration those factors which contribute to the rate of gas production in the dough, and also the dough properties which function in retaining the gas produced.

Gas production is dependent, however, not on protein quality and quantity, but on other factors. Of these, diastatic activity is of major importance, and strong and weak flours differ markedly in their content of diastatic enzymes (16). The ability of these to change starch to sugar provides the substrate from which the added yeast enzymes produce carbon dioxide. This activity is of particular importance during the later stages of fermentation (19), and the continued functioning of these enzymes constitutes one of the main differences between strong and weak flours as has been pointed out by Wood (19), and by Baker and Hulton (4). However, a flour deficient in diastase may be improved by the addition of diastatic preparations (6). It must also be borne in mind that gas cannot be produced without the help of the yeast enzymes which are added to the flour. In consequence, ammonium salts and phosphates present in the flour have a definite effect on gas production by virtue of their function as yeast stimulants (1,19).

Gas retention, on the other hand, is definitely related to the gluten proteins and to the effect of other flour constituents on their behaviour. Thus Wood (19) has pointed out that the effect of inorganic salts on the colloidal properties of the gluten is of considerable importance in gas retention. He finds that strength is associated with a high ratio of protein to inorganic salts, and he suggests that variations in this ratio may explain the different physical behaviours of the gluten of strong and weak flours.

The effect of hydrogen ion concentration on the colloidal properties of the gluten also plays a part in gas retention. This fact was illustrated by the investigations of the effect of ageing on the baking quality of flours (1,18). Changes in hydrogen ion concentration occur during this process, and the more acid reaction which results has a beneficial effect on the gas-retaining properties of the gluten.

The effect of lipoids, notably the phosphatides, upon the gluten network has also received attention (10,21,22). Working (21) suggests that moderate amounts produce a greater ductility in the gluten, thus allowing for more ready expansion. Some low-grade flours, on the other hand, contain an excess of phosphatides which creates a shortness in the dough and consequently a poorer loaf. Further proof of the effect of these compounds was obtained by Johnson (10), who extracted various flours with ether and obtained a larger loaf than from untreated controls. The greatest increases occurred with the lower grade flours. It must be noted, however, as pointed out by Working (21), that the absolute ether used probably did not extract all the phosphatides, and that had this happened a poorer loaf would probably have resulted. Working also suggests (22) that the efficiency of potassium bromate as an improver may be due to its ability to liberate phosphatides when these are deficient in the free state.

Methods for the measurement of gas production and retention were devised by Bailey and Weigley (2) and improved by Bailey and Johnson (3). The former measured only the escaping gas by absorbing it from a current of air which had been passed through the chamber containing the fermenting dough. The latter, by using one aliquot of dough for the direct measurement of its increase in volume and a second aliquot for measurement of the escaping gas, obtained a much more comprehensive series of data, since the sum of these two quantities gave an indirect measurement of the total gas produced.

The data obtained by these methods have been used, with excellent results, for comparing the characteristics of different flours. Bailey and Weigley (2) suggest that the loss of carbon diOxide per unit increase in dough volume forms a useful measure of the retention capacity of the dough. They suggest further that, under carefully controlled conditions, the method might show important correlations between gas retention and flour quality. Bailey and Johnson (3) find that the optimum period of fermentation of a dough may be determined by noting the time at which a sudden increase in gas escape occurs during fermentation. The method has also been used by Karacsonyi and Bailey (12) in their study of the effect of overgrinding on flours, and St. John and Bailey (17) and St. John and Hatch (18) used it in their investigations of the effect of dry skim milk and of ageing upon gas production and retention. The value of the method has thus been clearly demonstrated.

In the present research an attempt has been made to devise an improved method of measuring gas production and retention. The method developed has been applied to the investigation of the effect of (a) different pressures, (b) various improvers, and (c) kneading on gas production and retention. A study has also been made of the relation between gas production and retention in doughs and loaf volume.

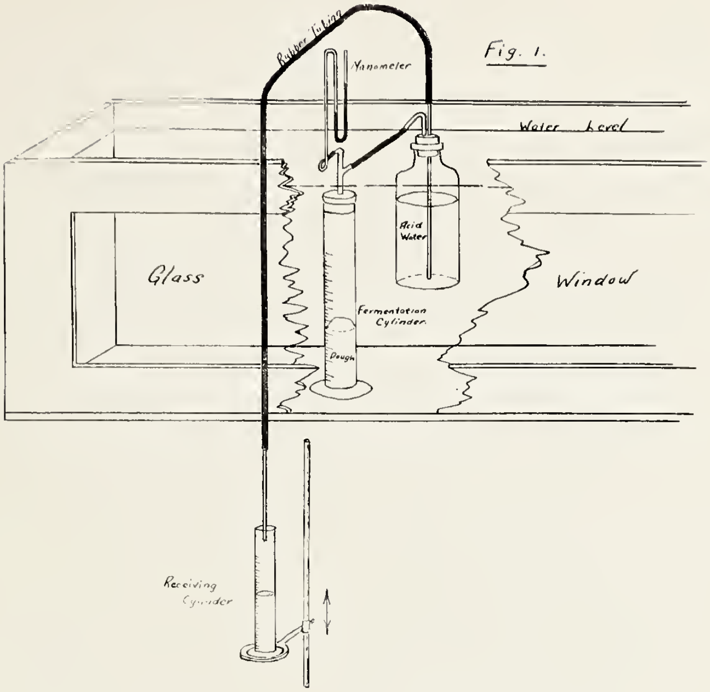
As far as we are aware no work has yet been carried out on the first two of these problems. The effect of kneading, however, has been investigated incidentally by Bailey and Weigley (2) and by Karacsonyi and Bailey (12). The results they obtained seemed to warrant a further investigation of this problem, more particularly since kneading forms an important part of all commercial baking.

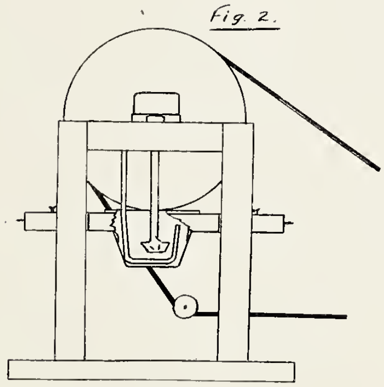
## APPARATUS

The apparatus devised for these investigations is shown in Fig. 1. It consists essentially of a fermentation chamber connected to a reservoir filled with acidulated water which is displaced by the gas evolved by the dough. The water is carried off by an adjustable syphon and collected in a graduated cylinder, thus giving a direct measurement of the total gas evolved. A graduated cylinder is also used as a fermentation chamber and the volume of the dough can therefore be read directly.

The pressure within the system is adjusted by raising or lowering the syphon until the manometer, which is connected directly to the fermentation chamber, registers the required pressure. The temperature is controlled by immersing the fermentation chamber and water reservoir in a large constant temperature bath at 30 degrees $\pm$ 0.2 degrees C. The reservoir is held in place in the bath by a clamp and the fermentation cylinder, to facilitate handling, is merely weighted down by a lead collar about its base. Eight units are placed in the same bath, thus making it possible to run duplicate determinations on four flours simultaneously.

A mechanical mixer was also contructed. The working parts (Fig.2) consist of a pair of rotating vanes on an inner arm, and a revolving, hook-shaped outer arm. In operation, the vanes press the dough ingredients downwards against the outer arm, which moves in the opposite direction, producing




Figures 1 and 2. The apparatus.
The fermentation apparatus. Fig. 1.
The mixer. Fig. 2.

a rolling and twisting movement in the dough. A homogeneous dough free from lumpiness was invariably produced.

## MATERIALS

The following flours were used throughout the investigations.

A. A commercial soft spring wheat flour.

B. A commercial soft winter wheat flour.

C. A commercial hard spring wheat flour.

D. A mixture of good quality flours milled in the laboratory from hard spring wheats.

The four flours were baked into bread in order to obtain data on their baking quality. Table 1 gives the results obtained. It will be noted that the flours cover a wide range of baking qualities and show considerable differences in their reaction towards various improvers.

Table 1. - Volumes produced by flours A,B,C, and D. with different formulae.

| Formula. | Loaf volumes from 100 g. doughs | | | |
|---|---|---|---|---|
| | Flour A | Flour B | Flour C | Flour D |
| | cc. | cc. | cc. | cc. |
| Simple | 486 | 455 | 512 | 628 |
| Bromate 0.0005% | 550 | 528 | 517 | 656 |
| " 0.0010% | 583 | 575 | 546 | 680 |
| " 0.0020% | 594 | 536 | 528 | 616 |
| Maltose 1% | 518 | 472 | 531 | 649 |
| " 2% | 532 | 495 | 567 | 657 |
| " 4% | 556 | 511 | 606 | 655 |
| " 6% | 573 | 509 | 646 | 692 |
| Maltose 1%, phosphate 0.05% | 555 | 533 | 648 | 712 |
| " 2% " 0.05% | 527 | 493 | 626 | 622 |
| " 4% " 0.05% | 554 | 499 | 607 | 690 |
| " 6% " 0.05% | 567 | 511 | 652 | 719 |

## METHOD

The formula used throughout these investigations was as follows:

Flour ................................ 50 g.

Yeast ................................ 1.5 g.

Sugar ................................ 1.25 g.

Salt ................................. 0.5 g.

Water - to the required consistency.

The weight of flour was corrected to a basis of 86.5% dry matter (13.5% moisture); determinations of the moisture content were made periodically to check up on changes due to atmospheric conditions. The yeast was made up into a suspension in lukewarm water immediately before using, and a stock of salt-sugar mixture was kept on hand and made up when required.

The flour, salt and sugar solution, and yeast suspension were measured into the mixing bowl and enough water added to bring the resulting dough to the right consistency as determined in a previous mixing. The ingredients were mixed mechanically for 4 minutes. The dough was then taken out, moulded into a cylindrical shape by hand, placed in the fermentation cylinder, and tamped down firmly with a stick. The cylinder was then connected up in the bath as shown in Fig. 1, the syphon having been previously filled. The pressure within the system was then adjusted by lowering the syphon until the manometer registered the correct pressure. At this stage the volume of the dough and of the water in the receiving cylinder was noted for use in correcting succeeding readings. These were taken every 15 mins., usually over a period of 5 hours.

Upon rising, the dough formed a convex meniscus in the measuring cylinder. It was therefore difficult to measure the true volume of the dough, but experiment showed that a fairly accurate value was obtained by averaging the readings for the upper and lower limits of the meniscus. This method was accordingly

adopted.

Since duplicate determinations on four flours were made concurrently, it is obvious that a considerable period of time elapsed between the mixing of the first dough and the hooking up of the last fermentation cylinder. The possibility of misinterpreting data through errors caused by rank in mixing and the above time factor, was eliminated by rotating the order of mixing of the four flours throughout each series.

## EXPERIMENTAL

### Preliminary

The apparatus and method were not completely standardised until the following minor problems had been solved by experimental methods.

#### Size of Fermentation Cylinders

Data obtained by fermenting 50 g. and 100 g. doughs in 500 cc. and 1 litre measuring cylinders are given in Table 11.

Table 11. - Effect of size of cylinders upon dough volume

| Weight of flour. | Final volume of dough. | |
|---|---|---|
| | ½ litre cylinder. | 1 litre cylinder. |
| g. | cc. | cc. |
| 50 | 250 | 255 |
| 50 " | 255 | 265 |
| 100 | 470 | 540 |
| 100 " | 498 | 570 |

" Together with 4 percent of maltose.

With both quantities of dough a larger final volume was obtained in the 1 litre cylinders, but the 500 cc. cylinders showed a smaller percentage difference between duplicate determinations. Each size of cylinder had its own particular advantage and disadvantage.

The smaller cylinders were finally chosen for several reasons. They were more easily handled in the water bath, and a larger number could be used without crowding the bath or impeding the proper circulation of the water init. Their lower heat capacity and smaller diameter allowed both them and their contents to attain the temperature of the bath more quickly. They had also the further advantage that the volume of the dough in them could be read much more accurately than with the larger cylinders.

Weight of Flour.

Data giving the maximum volume obtained by doughs mixed from 50 g. and 100 g. of flour are shown in Table 111.

Table 111. - The effect of weight of flour upon dough volume.

| Volume of cylinder | Final Volume of dough. | |
|---|---|---|
| | 50 g. of flour. | 100 g. of flour. |
| l. | cc. | cc. |
| ½ | 250 | 470 |
| ½ | 257 " | 498 " |
| ½ | 240 "" | 398 "" |

" Together with 4 percent of maltose.
"" Flour D.

The smaller doughs attained a greater comparative volume. They were selected for this reason and also because the quantity of some of the special flours to be used in the investigations was limited.

This experiment proved the necessity of standardizing the weight of flour used in all experiments. Reference to Table 111 will show that the final volumes attained by the doughs from the two quantities of flours were not proportional to the initial weights. It would therefore be impossible to make direct comparisons of data obtained in experiments in which different weight of flour were used.

Effect of Greasing Fermentation Cylinders.

It seemed probable that greasing the inside of the fermentation cylinder, by preventing the dough from adhering to the walls, might increase the rate of rising and the maximum volume attained by the dough. Previous observations on ungreased cylinders had shown that the dough by adhering to the walls prevented an accurate estimation of its volume at the end of the fermentation period. At this time the dough begins to fall, the convex top recedes and finally forms a concave meniscus, thus preventing an accurate estimation of volume.

The data obtained from one of several experiments on the fermentation of doughs in greased and ungreased cylinders are given in Table 1V.

Table IV. - Comparison of volumes of fermenting doughs in greased and ungreased cylinders.

| Time. | Ungreased Cylinder. dough menisci lower. | Ungreased Cylinder. dough menisci upper. | Greased Cylinder. dough menisci lower. | Greased Cylinder. dough menisci upper. |
|---|---|---|---|---|
| min. | cc. | cc. | cc. | cc. |
| 15 | 55 | 100 | 45 | 100 |
| 30 | 80 | 108 | 65 | 108 |
| 45 | 112 | 135 | 121 | 145 |
| 60 | 142 | 160 | 172 | 197 |
| 150 | 243 | 263 | 245 | 263 |
| 165 | 245 | 258 | 250 | 265 |
| 180 | 247 | 260 | 253 | 267 |
| 195 | 250 | 263 | 255 | 270 |

As had been anticipated, the rate of rise and the maximum volume attained by the dough were both increased. This, however, was offset by the difficulty of accurately duplicating results with greased cylinders, due doubtless to the impossibility of greasing all cylinders equally. The dough absorbed the grease as it rose, and the dough in both greased and ungreased cylinders showed the same concave meniscus when they began to fall. As a result of these findings cylinders were not greased for the remaining investigations.

## The Effect of Different Pressures upon Gas Production and Retention.

In the cooperative experiments conducted under the auspices of the Associate Committee on Grain Research at Winnipeg, Saskatoon, and Edmonton, persistent

differences in the volumes of loaves baked from the same flours by standard methods were obtained at the three stations. These differences are shown in Table V.

It will be observed that the loaf volumes bear an indirect relation to the altitude at the three stations. This suggested that differences in baking technique might not be wholly responsible for these variations, but that differences in pressure, due to differences in altitude, might also play a part by their effect on the gas retaining properties of the doughs. It seemed reasonable to suppose that, according to Henry's law, the greater the pressure during fermentation, the greater the volume of gas which would be retained by the liquid phase of the dough.

Table V. - Comparison of loaf volumes obtained from the same flours at three stations.

| Flour | Formula | Loaf volume, average of 25 tests. Winnipeg altitude, 760 ft. | Saskatoon altitude, 1690 ft. | Edmonton altitude, 2158 ft. |
|---|---|---|---|---|
| | | cc. | cc. | cc. |
| Purity | Simple | 629 | 597 | 513 |
| | Bromate | 678 | 648 | 562 |
| Sterling | Simple | 557 | 551 | 493 |
| | Bromate | 785 | 732 | 650 |
| Huron | Simple | 600 | 540 | 514 |
| | Bromate | 698 | 696 | 586 |
| Expt. | Simple | 572 | 510 | 499 |
| | Bromate | 645 | 625 | 570 |

In order to understand the reasoning which follows a clear picture of the changes which occur during the fermentation of a dough and its subsequent baking must be borne in mind. In round figures, the average 100g. dough has an initial volume of 140 cc. After fermentation this has increased to 300 cc. and the dough therefore contains about 150 cc. of carbon dioxide. When the dough is placed in the oven this gas expands and, with the aid of the steam from the water in the dough, produces a final loaf volume of 550 cc. These volumes vary with different flours but the final loaf volume will always depend largely upon the amount of gas retained after fermentation.

A 100-g. dough made from a strong flour contains approximately 70 g. of water. At Edmonton, with an average atmospheric pressure of 701 mm., 70 g. of water at 30 degrees C. would dissolve 40.7 cc. of carbon dioxide, measured at normal temperature and pressure. At Winnipeg, with an average of 740 mm., 43.3 cc. would be dissolved. Since the average 100-g. dough contains about 160 cc. of carbon dioxide it is obvious that changes in this volume of the order of 2.6 cc., which might result from the different atmospheric pressures at Winnipeg and Edmonton, would have no appreciable effect upon the final loaf volume. In addition, it must be pointed out that though a greater weight of carbon dioxide is dissolved in the aqueous phase at the higher pressure, when this is driven out of solution by the increased temperature of the oven, it expands less than would an equal weight of gas at a lower pressure. Calculation shows that the final effect on loaf volume of the additional 2.6 cc. of gas held in solution at 740 mm. would, in this way, be reduced to 0.6 cc. These theoretical calculations show, therefore, that differences due to pressure changes in the amount of gas retained in the liquid phase of the dough fail to explain the persistent relationship between loaf volume and altitude found at the three stations.

No other factors which might explain these differences suggested themselves. It was thought therefore, that pressure might have some obscure effect on the gas-retaining power of the dough, other than that on the solubility of the gas in the liquid phase. The investigation of this interesting problem was therefore considered necessary.

The apparatus devised could be adjusted to give pressures from 670 to 760 mm. By working over this wide range it seemed probable that such differences as occurred would be sufficiently large for accurate measurement, and that the exaggerated picture obtained might serve to elucidate the results of actual experience.

## Experimental Results.

In these experiments measurements of gas production and retention were carried out at 670, 690, 700, 710, 730 and 760 mm. on four different flours, The data obtained for gas production on one flour are given in Table Vl. The other three flours gave similar results. The figures reported in Table Vl are those for the volumes of gas corrected, from the pressure at which they were observed, to 760 mm. in order that true comparisons may be made.

Table Vl. - Gas production from flour C. at varying pressures.

| Time. | Volume of gas measured at pressures indicated and corrected to 760 mm. | | | | | |
|---|---|---|---|---|---|---|
| | 670 mm. | 690 mm. | 700 mm. | 710 mm. | 730 mm. | 760 mm. |
| min. | cc. | cc. | cc. | cc. | cc. | cc. |
| 15 | 19 | 15 | 15 | 15 | 12 | 9 |
| 60 | 127 | 113 | 118 | 120 | 115 | 106 |
| 120 | 309" | 281" | 286" | 295" | 287 | 270 |
| 180 | 436 | 409 | 444" | 402" | 428 | 392 |
| 240 | 541 | 524 | 547 | 570 | 537 | 495 |
| 300 | 634 | 606 | 629 | 664 | 621 | 581 |

" From interpolated values.

The data obtained for the increase in dough volume on the same flour at the same pressures are given in Table Vll. The observed values have also been corrected to 760 mm., since it was found experimentally that the dough volume obeyed the gas laws fairly closely when the dough was fully expanded.

Table Vll. - Gas retention in doughs made from Flour C at varying pressures.

| Time | Volumes measured at pressures indicated and corrected to 760 mm. | | | | | |
|---|---|---|---|---|---|---|
| | 670 mm. | 690 mm. | 700 mm. | 710 mm. | 730 mm. | 760 mm. |
| min. | cc. | cc. | cc. | cc. | cc. | cc. |
| 15 | 10 | 7 | 6 | 7 | 9 | 7 |
| 60 | 107 | 96 | 102 | 102 | 107 | 96 |
| 120 | 138 " | 143 " | 138 " | 145 " | 155 | 156 |
| 180 | 158 | 161 | 159 | 158 " | 179 | 177 |
| 240 | 163 | 169 | 170 | 166 | 182 | 186 |
| 300 | 163 | 173 | 173 | 169, | 187 | 183 " |

" From interpolated values.

## Discussion

In considering the figures for gas production, it must be remembered that these have not been corrected for the effect of changes in pressure, according to Henry's law, on the volume of gas dissolved in the water in the Winchesters. These corrections could not be calculated exactly since the composition of the gaseous phase and the quantity of water in the apparatus changed continuously. However, if an average condition is assumed, namely, when the gaseous phase is one-quarter carbon dioxide and three-quarters air, and when 300 cc. of water (equivalent to half that displaced in an average experiment) has been displaced from

the 2.5 litre Winchester, a calculation of the magnitude of the correction due to Henry's law can be made. This between pressures of 670 and 760 mm. is of the order of 46 cc. of gas, measured at 760 mm. and 30 degrees C. This covers the differences, shown in Table V1, between the volumes for gas produced at 670 and 700 mm. It is concluded, therefore, that differences in pressure have no appreciable effect on gas production in doughs.

It would appear from the data obtained that pressure has a marked effect upon the gas-retaining properties of fermenting doughs. Differences of as much as 27 cc. have been found in volumes of doughs fermented at 670 mm. and at 760 mm. No theoretical explanation of such differences has yet suggested itself.

It must be pointed out, however, that no great significance should be attached to these results since it appears that gas retention in doughs which have not been kneaded is not a true criterion of baking quality. The data recorded in Table V11 show that there is no correlation between gas retention or gas production in unkneaded doughs and loaf volume. This conclusion has been substantiated by further results obtained in other investigations, and reported later (Tables X1 and X11, pages 29 and 30). In view of this fact, and the experimental errors of the method, it is felt that no conclusions should be drawn until this whole problem has been reinvestigated.

Table V111. - Comparison of gas production and retention " in unkneaded doughs, with loaf volume.

| Flour | Loaf volume | Gas production | Gas retention |
|---|---|---|---|
| | cc. | cc. | cc. |
| A | 486 | 662 | 208 |
| B | 455 | 672 | 182 |
| C | 512 | 639 | 188 |
| D | 628 | 722 | 182 |

" Gas production values were taken at 4½ hrs. Gas retention values are the maximum increases in dough volumes.

## The Effect of Improvers on Gas Production and Retention in Unkneaded Doughs.

Improvers have two important functions in bread making. By supplying nutritive material they stimulate the yeast to greater activity, which results in an increase in the rate of gas production. They also promote gas retention by acting on the gluten proteins in such a way that their tenacity is increased whilst their elasticity remains sufficient to allow for free expansion.

In the following investigations all measurements were carried out at 30 degrees C. and 700 mm. Four flours were used and four different standard formulae, neamely:-

(a) Simple formula.
(b) Maltose formula, using 4% maltose.
(c) Maltose-phosphate formula, using 4% maltose and 0.5% ammonium dihydrogen phosphate.
(d) Bromate formula, using 0.001% potassium bromate.

The effects of three different improvers on four flours has thus been investigated. Of these, maltose and maltose-phosphate, have been thought to have their main effect on gas production through yeast stimulation, and bromate its main effect on gas retention by virtue of its action on the gluten proteins.

In Fig. 3 are given the graphs showing the effect of maltose and maltose-phosphate on the gas production and retention of both a strong and a weak flour. It will be seen that maltose decreased the initial rate of gas production but that this was soon increased to give a greater rate than that obtained without maltose. The final rate was maintained longer so that the volume of gas produced when maltose was added was eventually greater than when no improver was used. Similar but much more exaggerated effects were produced by maltose-phosphate. There were no significant differences in the effect of these improvers on the gas production of strong and weak flours.

Maltose also effected a slight increase in the dough volume. Here again maltose phosphate was more efficient, especially in the early stages of fermentation, when the volume of the treated dough increased much more rapidly than did that of the untreated dough, although the final volumes were almost the same.

The effects of using 1%, 2% and 6% concentrations of maltose were also studied. The results did not differ significantly from those obtained with 4% maltose.

In Fig. 4 are shown the gas production and retention curves for both a strong and weak flour, mixed according to the bromate formula. It will be observed that bromate has the same effect on both flours, namely, that it had little effect on gas production (9) and increased the gas retention. Similar results were obtained with the other two flours.

A study was also made of the effects of varying concentrations of bromate on gas production and retention. Three concentrations were used, namely, 0.0005, 0.001% and 0.002%. In Table lX are given the data for gas production after $1\frac{1}{2}$, 3 and $4\frac{1}{2}$ hours for four flours with the different concentrations of bromate. The results are extremely variable and the only conclusion that can be drawn from them is that, in general, bromate reduces gas production.

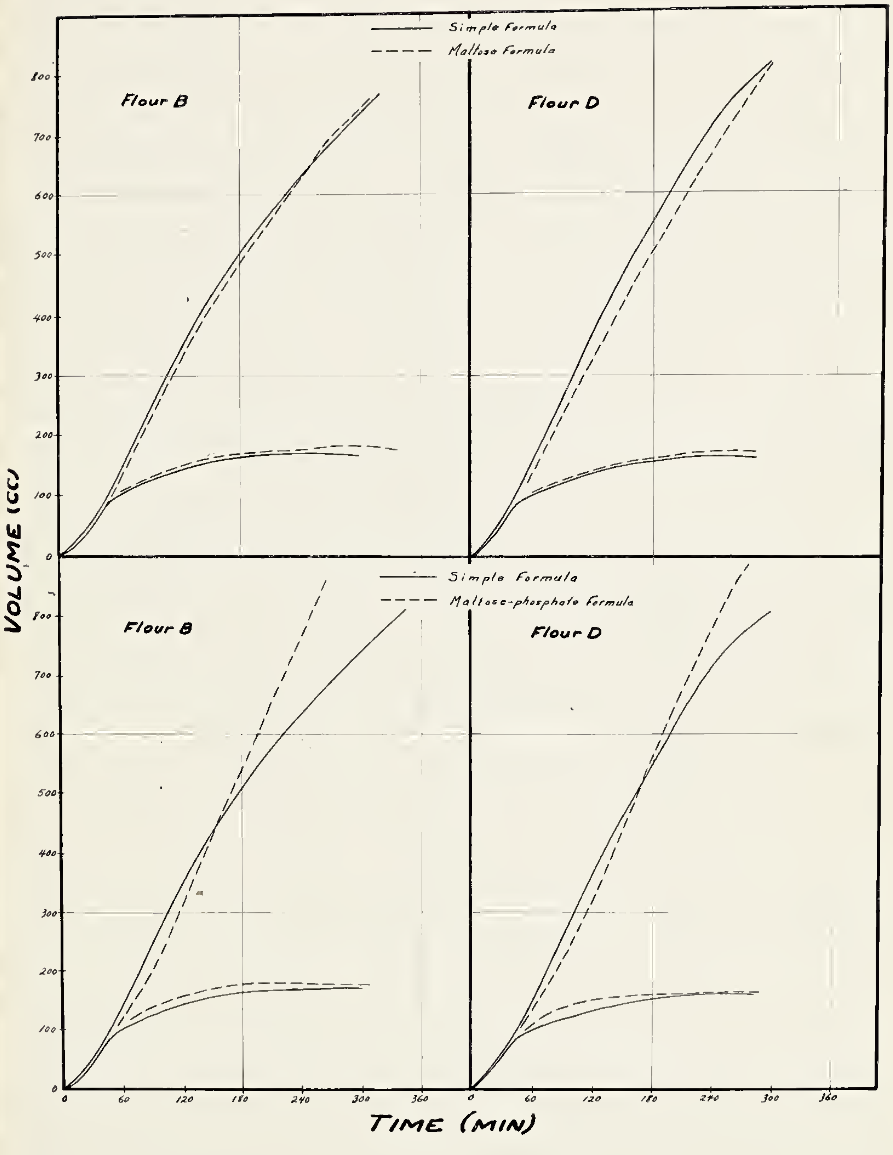



Figure 3. Comparison of the gas production and retention curves of a weak flour, B, and a strong flour D, using maltose and maltose phosphate with curves obtained by using the simple formula.

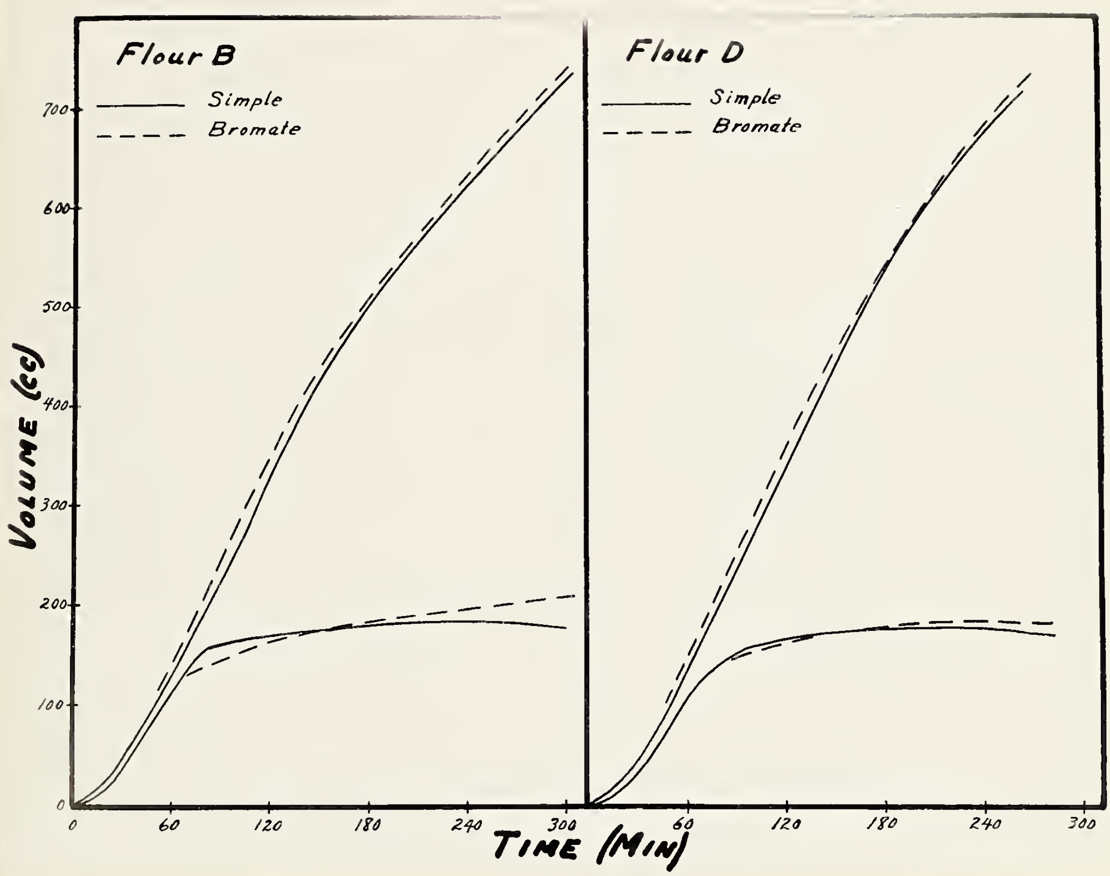



Figure 4. Comparison of the gas production and retention curves of a weak flour B, and a strong flour D using bromate, with curves obtained by using the simple formula.

Table IX. - Gas production in unkneaded doughs with varying concentrations of potassium bromate.

| | Flour A | | | Flour B | | | Flour C | | | Flour D | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Conc. of bromate. | 1½ hr. | 3 hr. | 4½ hr. | 1½ hr. | 3 hr. | 4½ hr. | 1½ hr. | 3 hr. | 4½ hr. | 1½ hr. | 3 hr. | 4½ hr. |
| % | cc. | cc. | cc. | cc. | cc. | cc. | cc. | cc. | cc. | cc. | cc. | cc. |
| 0.0000 | 230 | 496" | 662 | 226" | 500 | 672 | 222 | 482" | 639 | 225 | 526" | 722 |
| 0.0005 | 239 | 465 | 641 | 248 | 486" | 652" | 231 | 468 | 632" | 278 | 545" | 715" |
| 0.0010 | 243 | 490 | 664 | 256 | 506 | 687 | 241" | 483 | 645 | 252" | 532 | 741" |
| 0.0020 | 225 | 466 | 625" | 251 | 500 | 676" | 231 | 470 | 617" | 243 | 519 | 728" |

" Interpolated and extrapolated values.

In Table X are given a similar set of data for dough volume with the various treatments. Here again it will be observed that the results are so variable that no conclusions can be drawn from them except that each flour appears to be affected to a different extent by any definite quantity of potassium bromate. For instance, Flour B apparently benefits to the greatest extent by the larger quantities of the improver while the stronger flours, C and D benefit little by any of the quantities which were added.

Table X. - Gas retention in unkneaded doughs with varying concentrations of potassium bromate.

| Conc. of | Flour A | | | Flour B | | | Flour C | | | Flour D | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| bromate. | 1½ hr. | 3 hr. | 4½ hr. | 1½ hr. | 3 hr. | 4½ hr. | 1½ hr. | 3 hr. | 4½ hr. | 1½ hr. | 3 hr. | 4½ hr. |
| % | cc. | cc. | cc. | cc. | cc. | cc. | cc. | cc. | cc. | cc. | cc. | cc. |
| 0.0000 | 175 | 194" | 209 | 159" | 178 | 179 | 140 | 173 | 183 | 152 | 172" | 174 |
| 0.0005 | 134 | 157 | 168 | 122 | 157" | 182" | 142" | 171 | 180 | 155 | 181" | 190" |
| 0.0010 | 160 | 177 | 198 | 142 | 180 | 200 | 140" | 164 | 177 | 145 | 178 | 182" |
| 0.0020 | 140 | 153 | 162" | 129 | 172 | 190" | 120 | 154 | 163" | 136 | 167 | 178" |

" Interpolated and extrapolated values.

These investigations completed, a sufficient body of data had been obtained for a study of the relation, if any, between gas production and retention of unkneaded doughs and loaf volume. The following tables were therefore drawn up. Table XI shows the loaf volume and the gas produced by the unkneaded doughs in 4½ hours. The data for four flours are reported, the measurements having been carried out at 30 degrees C. and 700 mm.

A study of the data show that there is no correlation between loaf vol-

ume and gas production.

Table X1. - Comparison of gas production of unkneaded doughs with loaf volume.

| Formula | Flour A Loaf vol. | Flour A Gas prod. at $4\frac{1}{2}$ hr. | Flour B Loaf vol. | Flour B Gas prod. at $4\frac{1}{2}$ hr. | Flour C Loaf vol. | Flour C Gas prod. at $4\frac{1}{2}$ hr. | Flour D. Loaf vol. | Flour D. Gas prod. at $4\frac{1}{2}$ hr. |
|---|---|---|---|---|---|---|---|---|
| | cc. | cc. | cc. | cc. | cc. | cc. | cc. | cc. |
| Simple | 486 | 662 | 455 | 672 | 512 | 639 | 628 | 722 |
| Maltose | 556 | 675 | 511 | 688 | 606 | 673 | 655 | 749 |
| Maltose-phosphate | 554 | 861 | 499 | 874 | 607 | 816 | 690 | 895 |
| Bromate | 583 | 664 | 575 | 687 | 546 | 645 | 680 | 741 |

In Table X11 are given a similar set of data for loaf volume and maximum dough volume. Here again it will be seen that no correlation exists.

Table X11. - Comparison of gas retention in unkneaded doughs with loaf volume.

| Formula | Flour A Loaf vol. | Flour A Max. vol. of gas retained. | Flour B Loaf vol. | Flour B Max. vol. of gas retained. | Flour C Loaf vol. | Flour C Max. vol. of gas retained. | Flour D Loaf vol. | Flour D Max. vol. of gas retained. |
|---|---|---|---|---|---|---|---|---|
| | cc. | cc. | cc. | cc. | cc. | cc. | cc. | cc. |
| Simple | 486 | 209 | 455 | 182 | 512 | 188 | 628 | 182 |
| Maltose | 556 | 173 | 511 | 181 | 606 | 187 | 655 | 177 |
| Maltose-phosphate | 554 | 170 | 499 | 184 | 607 | 183 | 690 | 169 |
| Bromate | 583 | 208 | 575 | 209 | 546 | 181 | 680 | 179 |

It appears therefore that, if the baking test be accepted as a true criterion of quality in flours, then gas production and retention in unkneaded doughs bears no relation to quality. In these circumstances little, if any, significance can be attached to the results which have so far been reported, and further discussion of them will serve no useful purpose.

## The Effect of Kneading upon Gas Production and Retention.

In routine baking tests on flours the dough is kneaded three times during the three-hour fermentation period. It is well known that good bread cannot be produced without this kneading and it follows, therefore, that it must result in some important changes in the dough. Moreover, it was thought that the results of previous experiments might have been vitiated by the fact that the doughs used were not kneaded, and that a correlation might be found to exist between gas production and retention in kneaded doughs and loaf volume. In consequence, experiments designed to study the effect of kneading on gas production and retention were outlined.

### Method

The four flours, mixed according to the simple formula, were used in this investigation. All measurements were carried out at 30 degrees C. and 700 mm.

In each experiment four pairs of identical doughs were used. The first pair were placed in the apparatus immediately after mixing. The second pair were allowed to ferment in a cabinet at 30 degrees C, for $1\frac{3}{4}$ hours. They were then kneaded and transferred to the apparatus. The third pair were treated similarly but received two kneadings at intervals of $1\frac{3}{4}$ hours and $\frac{3}{4}$ hour before being transferred. The last pair were subjected to three kneadings at intervals of $1\frac{3}{4}$ hours, $\frac{3}{4}$ hour and $\frac{1}{2}$ hour, as in the routine baking tests, before being placed in the apparatus.

The data obtained were graphed to facilitate comparison. By combining the curves for the last three pairs of doughs, a composite picture of the behaviour of a dough, with three kneadings during fermentation, was obtained. This was compared with the curve for an unkneaded dough.

Since the graphs thus obtained are a little difficult to understand, it seems advisable to analyse the methods by which they were obtained. The gas production curves (Figs. 5a and 5b) are self-explanatory. The gas-retention or dough-volume curves, (Figs. 5c and 5d), are a little more complex. These are composite curves obtained by superimposing the graphs obtained from three duplicate sets of doughs which had been subjected to one, two and three kneadings respectively, as explained above. The method by which the curves are built up is illustrated in Fig. 6. Fig. 6a shows the curve for an unkneaded dough; Fig. 6b the curve for a dough kneaded once, the vertical drop in the curve representing the immediate decrease in dough volume which occurs in kneading. Similarly Fig. 6c shows the curve for a dough kneaded twice, and Fig. 6d that for a dough kneaded three times. Fig. 6e shows the composite curve obtained by superimposing the curves of Figs. 6a, 6b, 6c and 6d.

## Experimental Results.

In Table X111 are given the data for gas production and retention of kneaded doughs of the four flours, together with the volumes of loaves produced from them. No correlation exists between gas production and loaf volume. On the other hand, gas retention or dough volume is correlated with loaf volume. This conclusion has been substantiated by the results of further experiments, which will be reported later. With these facts in mind a discussion of the results of the present investigation may be proceeded with.

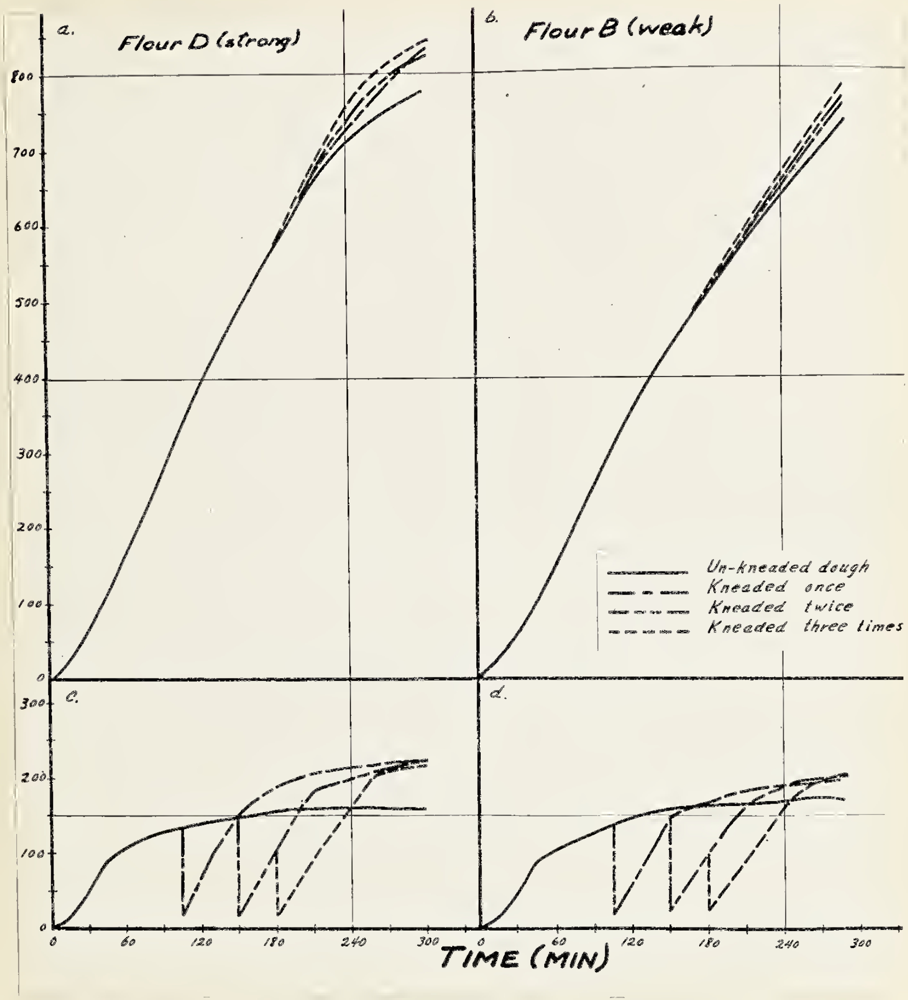



Figure 5. The effect of kneading a strong and a weak flour.

a and b. Gas production.

c and d. Gas retention.

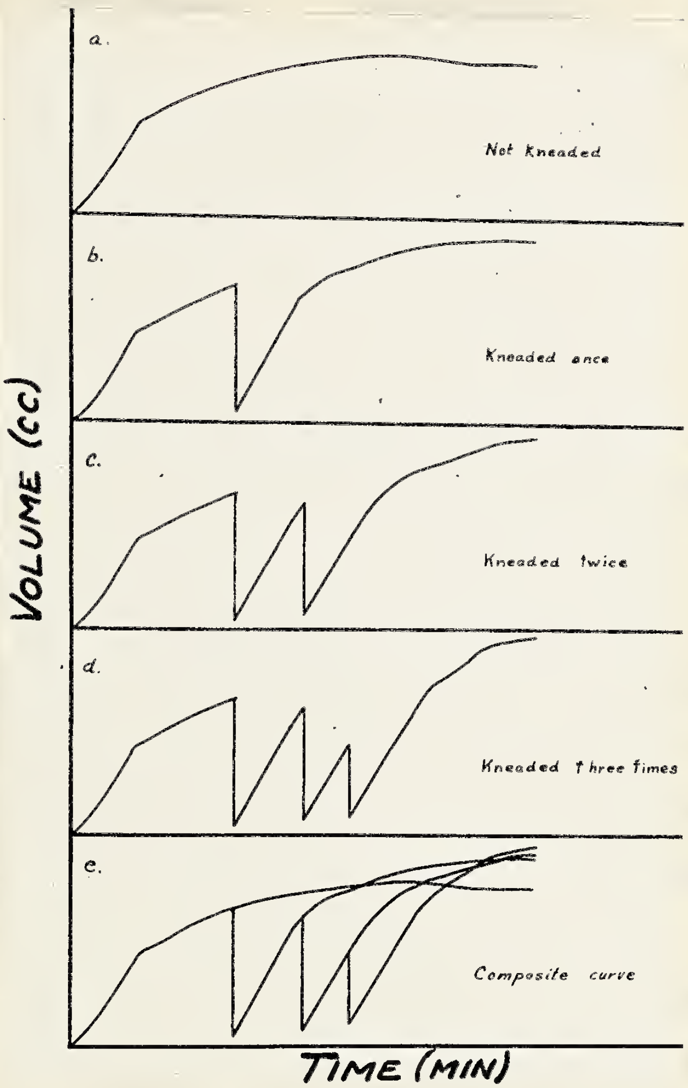



Figure 6. The effect of kneading upon a gas retention curve.

Table XIII. - Comparison of gas production and retention" in kneaded doughs.

| Flour | Loaf volume | Gas production | Gas retention. |
|---|---|---|---|
| | cc. | cc. | cc. |
| A | 486 | 732 | 205 |
| B | 455 | 738 | 200 |
| C | 512 | 727 | 202 |
| D | 628 | 813 | 222 |

" Gas production values were taken at $4\frac{1}{2}$ hrs. Gas retention values are the maximum increases in dough volumes.

A comparison of the curves (Fig. 5) for kneaded and unkneaded doughs will show that kneading increased the rate of gas production, sustained the initial rate longer, and thus increased the total gas production. In all these respects, the effect of two and three kneadings was correspondingly greater than that of one kneading.

These changes are comparatively unimportant by comparison with those produced in the volume of gas retained by the dough. This was increased by an amount which would have been extremely significant had the doughs been baked into bread. A study of the curves will show further, that two and three kneadings did not, in general, produce corresponding increases in the amount of gas retained by the dough. In this respect one kneading appears to have been suffifient.

Interesting results have been obtained by studying the effect of kneading on the properties of doughs made from strong and weak flours. In Fig. 5

the gas-production and dough-volume curves, for a weak flour (B) and a strong flour (D), are shown side by side.

Kneading increased the rate of gas production and the volume of gas produced with both weak and strong flours. The effect of two and three kneadings was correspondingly more marked than that of one kneading. It will be observed that the main difference between strong and weak flours, with respect to gas production, is that in the former the initial rate of gas production is maintained throughout the fermentation period, whilst in the latter it falls off after about 4 hours. In this respect kneading had a beneficial effect on weak doughs since the initial rate of gas production was maintained longer in kneaded than in unkneaded doughs. It must be pointed out, however, that these changes in gas production are of very little actual significance, since both the strong and weak flours produced a relatively large excess of gas, most of which escaped.

Remarkable differences between strong and weak flours were illustrated by the effect of kneading on the gas-retaining properties of their doughs. References to Figs. 5c and 5d will show that the weak dough (B) and the strong dough (D) retained approximately the same amount of gas when both were fermented without kneading. The results with kneading, on the other hand, provide a striking contrast. The gas retention of the strong dough was increased twice as much as that of the weak dough. This is a point of fundamental importance since, as has been pointed out elsewhere, the final loaf volume is dependent to a very large extent on the volume of gas retained in the dough after fermentation. The general validity of these results will have to be investigated.

## Discussion

The explanation of the increase in gas production produced by kneading is twofold. In the first place, the yeast cells spread throughout the dough, use up the substrate in their immediate vicinity, and thus reduce their gas-producing power. Kneading remedies this situation by bringing fresh substrate into contact with the yeast cells. In the second place, the yeast produces local concentrations

of alcohol, carbon dioxide and acids, which check the activity of the cells. Kneading reduces the local concentrations of these inhibitory substances and the yeast cells regain their original activity. With these considerations in mind, it is obvious that the gas production of both strong and weak flours will be affected similarly by kneading.

In order to understand the increased gas retention of doughs after kneading, it is necessary to keep their constitution in mind. A dough consists chiefly of starch particles, which are held together by the hydrated, net-like gluten micellae. This spongy framework is surrounded by water which is free for the solution of such added ingredients as salt and sugar, as well as the carbon dioxide, alcohol and acids produced by the yeast during fermentation. Immediately after mixing, the dough is tough, lacking in elasticity, and breaks readily. This is probably due to insufficient and uneven hydration of the gluten strands which causes weak points in the structure. When the first gas bubbles are formed, these weak spots expand and finally break, allowing the small gas bubbles to coalesce. The larger bubbles thus formed expand until the increased thickness of the walls make them somewhat more stable. This results in the coarse texture observed in unkneaded doughs. The low gas retention is explained by the low elasticity of the gluten and the relative instability of the large bubbles. The latter point is demonstrated by the ease with which these doughs collapse.

The initial fermentation period causes considerable improvement in the dough. The acids produced by the yeast, together with the mechanical action of the expanding gas, stimulate a further and more uniform hydration of the gluten proteins. When the dough is kneaded the improved elasticity allows it to rise more rapidly, and to attain a considerably greater volume than before. The gas is retained in smaller, more uniform bubbles, with thinner walls, resulting in the finer texture observed. Further kneadings produced no further increase in the dough volume, it must be considered that the maximum elasticity of the gluten is attained in the early stages of fermentation.

## The Effect of Improvers on the Gas Production and Retention in Kneaded Doughs

Since it has been shown that a correlation existed between loaf volume and gas retention in kneaded doughs, whereas none existed in unkneaded doughs, it seemed advisable to repeat the investigations of the effect of improvers on gas production and retention, using kneaded instead of unkneaded doughs.

### Experimental Results.

In these investigations the four flours and four formulae of previous studies were used. The method was essentially that used in the earlier investigation of the effect of kneading. In presenting these data the results of only one kneading are graphed in order to simplify the curves.

In Table XlV are given the data for loaf volume and gas production for four flours mixed according to four formulae. It will be observed that no correlation exists between loaf volume and gas production.

Table XlV. - Comparison of gas production" of kneaded doughs and loaf volume.

| Formula | Flour A | | Flour B | | Flour C | | Flour D | |
|---|---|---|---|---|---|---|---|---|
| | Loaf vol. | Gas prod. | Loaf vol. | Gas prod. | Loaf vol. | Gas prod. | Loaf vol. | Gas prod. |
| | cc. | cc. | cc. | cc. | cc. | cc. | cc. | cc. |
| Simple | 486 | 732 | 455 | 738 | 512 | 727 | 628 | 813 |
| Maltose | 556 | 802 | 511 | 744 | 606 | 746 | 655 | 842 |
| Maltose-phosphate | 554 | 842 | 499 | 842 | 607 | 776 | 690 | 870 |
| Bromate | 583 | 730 | 575 | 704 | 546 | 722 | 680 | 813 |

" Gas production values were taken at 4½ hours.

In Table XV are given similar data for loaf volume and maximum gas retention in the kneaded doughs. It will be found that a close correlation (r : 0.94 - 0.04) exists between loaf volume and gas retention. The latter thus serves as a criterion of baking quality, and the results of these experiments are therefore significant.

Table XV. - Comparison of gas retention" in kneaded doughs and loaf volume.

| Formula | Flour A | | Flour B | | Flour C | | Flour D | |
|---|---|---|---|---|---|---|---|---|
| | Loaf vol. | Gas ret. | Loaf vol. | Gas ret. | Loaf vol. | Gas ret. | Loaf vol. | Gas ret. |
| | cc. | cc. | cc. | cc. | cc. | cc. | cc. | cc. |
| Simple | 486 | 205 | 455 | 200 | 512 | 202 | 628 | 222 |
| Maltose | 556 | 245 | 511 | 221 | 606 | 250 | 655 | 271 |
| maltose-phosphate | 554 | 256 | 499 | 214 | 607 | 267 | 690 | 302 |
| Bromate | 583 | 258 | 575 | 250 | 546 | 235 | 680 | 274 |

" Maximum increase of dough volume.

- In Fig. 7 are shown the curves for gas production and retention in the kneaded doughs of the four flours, with and without maltose. It will be observed that the improver increased the rate of gas production in flour A but had very little effect on the other three flours.. When the improver was added to flours B and D, the doughs required a slightly longer time to attain their maximum rate of gas production, but when this was reached it was identical with the rate when no maltose was used. The addition of maltose sustained the rate of gas production longer, and thus increased the total volume of gas produced.

The effect of this improver on gas retention also differed with different flours. With the weakest flour, B, the gas retention was decreased slightly, whereas with the other three flours marked increased occurred, though the amount of increase was not related to strength. It is worth noting that in the strongest flour, D, maltose decreased the gas retention prior to kneading, but increased it significantly after kneading. This illustrates the danger of drawing conclusions as to the effect of an improver when only its action on unkneaded dough has been studied.

In Fig. 8 are shown similar curves for the four flours, with and without maltose-phosphate. It will be observed that this improver had effects similar to those of maltose, but that these were much more marked. Maltose-phosphate resulted in definite increases in the rate of gas production in the three weakest flours, but had very little effect on the strong flour D.

The effect of this improver on gas retention was also similar to, but more marked than, that of maltose alone. The flours were stimulated in the same order as with maltose; the weakest flour, B, was effected least, followed by flour A, D and C, in that order.

In Fig. 9 are shown the curves for the four flours, with and without bromate. The results with this improver were very similar with all four flours.

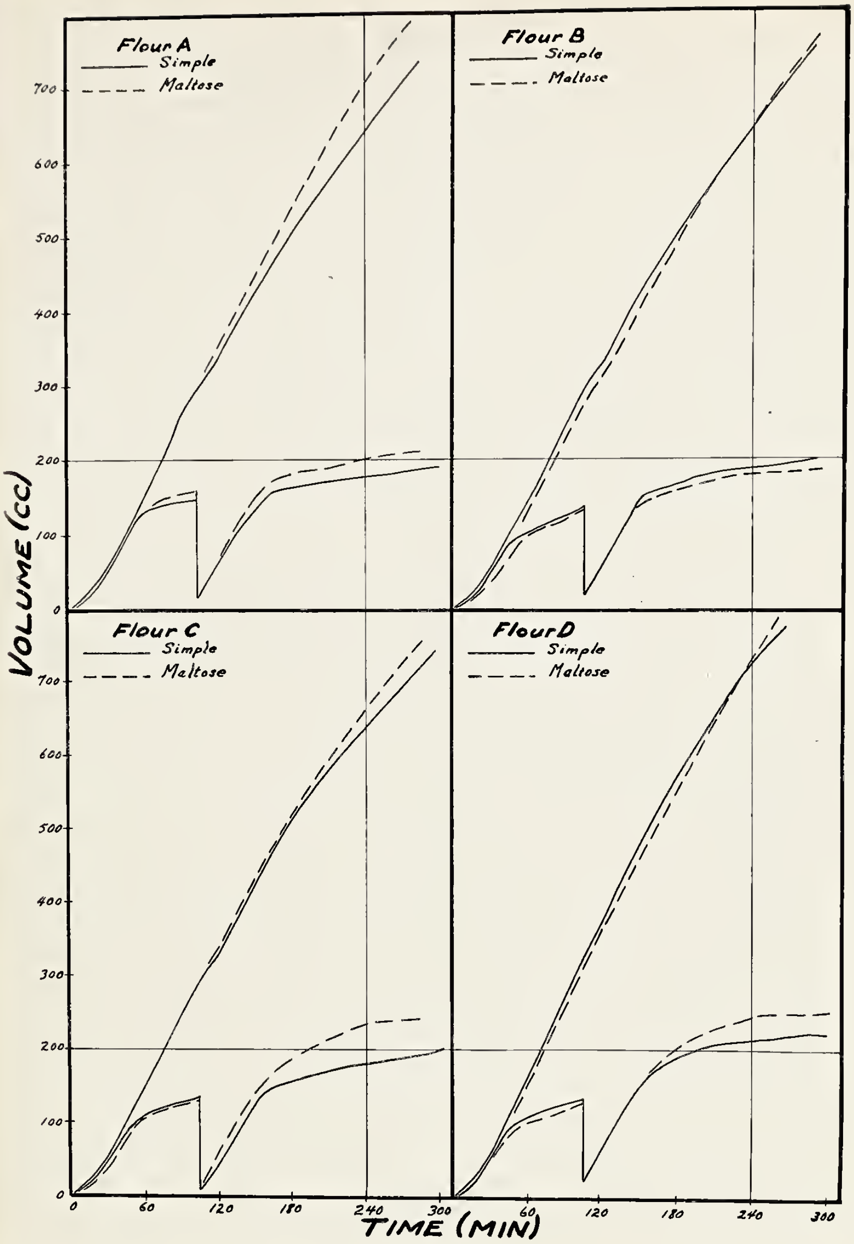



Figure 7. Comparison of the gas production and retention curves of kneaded doughs containing maltose with those of kneaded doughs mixed according to the simple formula.

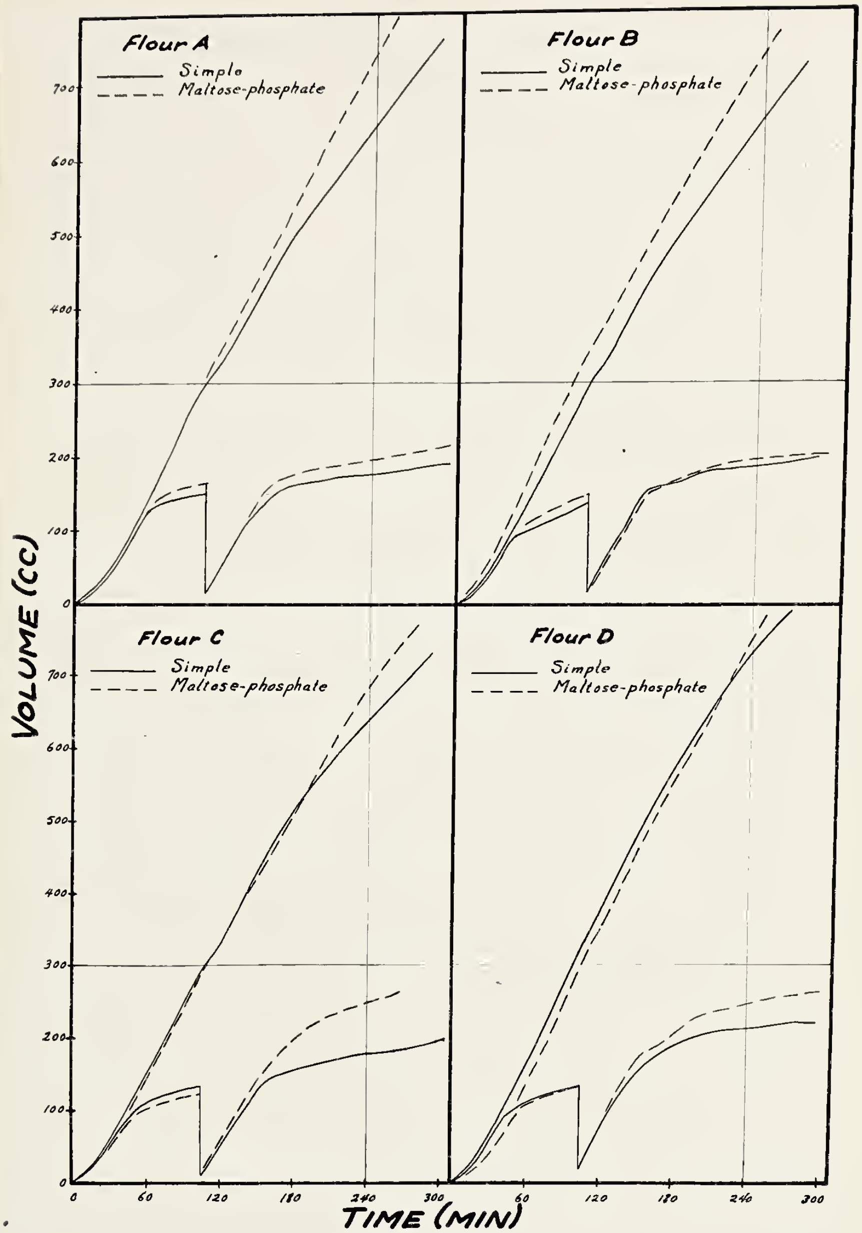



Figure 8. Comparison of the gas production and retention curves of kneaded doughs containing maltose-phosphate with those of kneaded doughs mixed according to the simple formula.

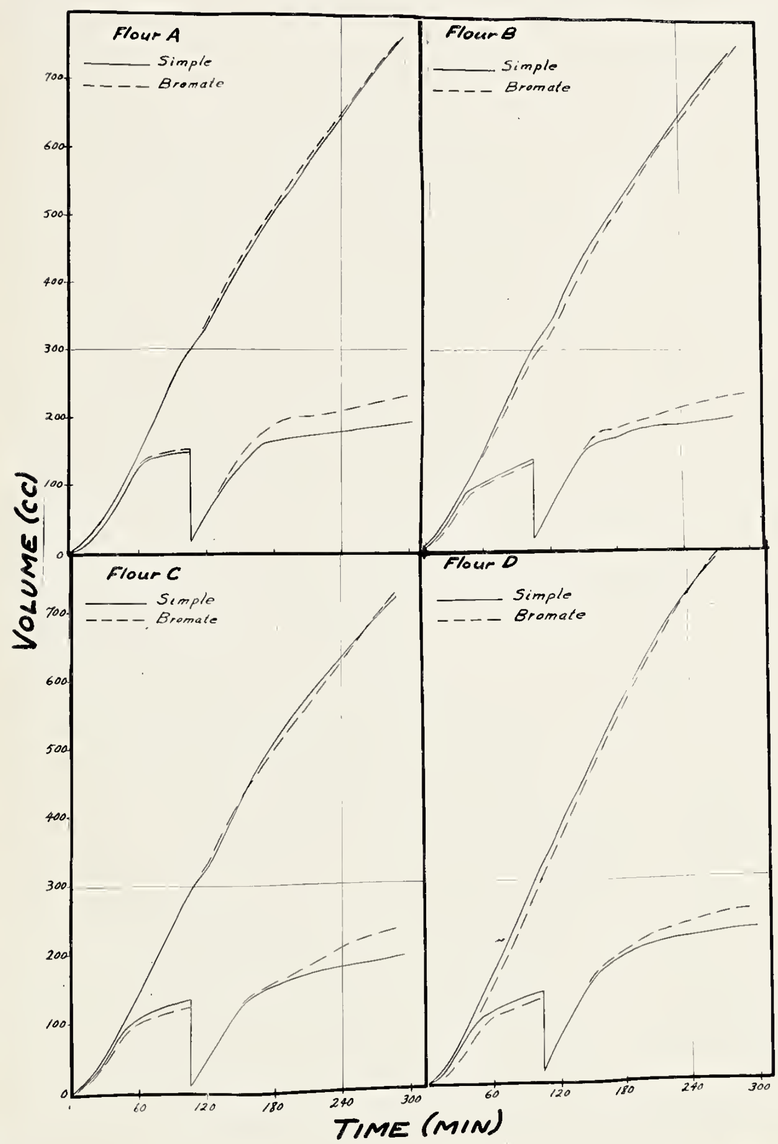



Figure 9. Comparison of the gas production and retention curves of kneaded doughs containing bromate with those of kneaded doughs mixed according to the simple formula.

Gas production was little affected, being reduced very slightly. The weaker flours A and B showed greater increases in gas retention than did the stronger flours. In this respect bromate was superior to the other two improvers, though with the stronger flours, especially C, maltose-phosphate produced the greatest increases in gas retention.

## Discussion

By far the most important fact established by these investigations is that the loaf volume is only related to gas retention when the dough is kneaded. This fundamental fact seems to have escaped the attention of previous investigators as no tables showing the relation between gas retention and loaf volume have been found in previous papers.

In all four flours worked with, the production of gas was more than adequate to give maximum expansion of the dough, hence no conclusions regarding dough behaviour when gas production is a limiting factor, can be drawn.

It has been generally held that maltose and maltose-phosphate have their main effect on gas production. Maltose acts directly on the yeast by supplying a readily available nutrient. The action of the phosphate ion is more obscure, but it is believed to have a direct stimulating influence on the growth of the yeast. This contention is not borne out by the results of these experiments since both improvers produced, in general, greater changes in gas retention. It must be concluded, therefore, that in the flours studied the activity of the yeast was not a limiting factor in baking quality.

The initial slowing up of the rate of gas production caused by these improvers, with some flours, is very interesting and not easily explained. It must be noted, however, that whether improvers were used or not, the gas production increased slowly at the beginning of the fermentation, and that it was not until some 45 minutes had passed that it attained its maximum rate. This rate was then held approximately constant for varying lengths of time with different

treatments. The addition of the two improvers mentioned above generally caused an increase in the time taken by the doughs to reach their maximum rate of gas production, but since this rate was then sustained longer, a greater volume of gas was finally produced. This appears to be contrary to theoretical expectations. It might be expected that gas production would be stimulated early in the fermentation period, since the yeast would have a large supply of the readily available nutrient maltose, and that when this was used up the rate would fall back again to that of doughs in which no improver had been used, since it would then be dependent entirely on the sugar produced from the starch by the diastatic enzymes. This was not so in the flours studied, with the possible exception of Flour A. It would appear, therefore, that in these flours the diastatic activity was sufficient to produce all the sugar required by the yeast. The interesting problem of the effect of these improvers on gas production will require further study, using a great variety of flours, before a satisfactory explanation of these experimental results can be given.

With the information available at present, it is impossible to offer any satisfactory explanation of the increase in gas retention in flours A, C and D, nor of the decrease in flour B, produced by maltose. The differences between treated and untreated doughs with flour B is small, and possibly insignificant. The increased gas retention with the other three flours, on the other hand, is comparatively large. It therefore deserves particular attention, more particularly since it is contrary to theory, which holds that maltose has its main effect on gas production. Further investigation of this interesting problem will be necessary.

The increase in gas retention produced by maltose-phosphate was very marked with three of the four flours. The explanation of this may be that the addition of ammonium dihydrogen phosphate stimulated protein hydration. The phosphate ion, by virtue of its effect on hydration and other colloidal pro-

perties, may also have contributed its effect.

The results obtained with potassium bromate are in accord with previous findings. Bromate has been known to have little effect on gas production, and to decrease it slightly if it produces any change. The increased gas retention observed when bromate was added must be attributed to its effect on the colloidal properties of the protein. At the present time it is not known whether this is a direct or indirect effect. As the concentration of bromate used in these experiments was very low, never more than 0.002%, it seems unlikely that it stimulated protein hydration directly. It seems more probable that it caused an oxidation of surface-active lipoids, which cover the protein-water interface and thus prevent uniform hydration. By this means the activity of the lipoids was reduced by oxidation and their inhibition of hydration decreased. That this would occur, seems highly probable, although there is at present no direct experimental evidence with reference to the oxidation of flour lipoids.

# SUMMARY


1. A new method has been developed for the direct measurement of gas production and retention in doughs throughout the fermentation period, and this has been applied to the investigation of four problems.

2. In the four flours studied, it has been found that gas production is not a limiting factor and is not related to baking quality as measured by loaf volume.

3. Gas retention in kneaded doughs is closely related to loaf volume. On the other hand, gas retention in unkneaded doughs is not related to loaf volume, a fact which has apparently escaped the attention of previous workers in this field.

4. Studies of the effect of pressures varying from 670 mm. to 760 mm. on fermenting doughs, show that pressure has no effect on gas production. An increase in pressure from 670 mm. to 760 mm. has been shown to produce an increase in the volume of gas retained by the dough. However, the evidence obtained is not considered sufficiently reliable to establish this change as significant.

5. Kneading has been found to increase gas production slightly and gas retention to a very marked extent. The significance of the changes due to kneading are well illustrated by the fact that gas retention in kneaded doughs is related to loaf volume, whereas that of unkneaded doughs is not.

6. The study of the effect of improvers on gas production and retention has produced interesting results. Maltose and maltose with ammonium dihydrogen phosphate, which have been thought to have their main effect on gas product-

ion, have been shown to produce much more significant increases in gas retention, more particularly with strong flours. Bromate, as has been previously thought, has its main effect on gas retention. It produces greater increases with weak flours than with strong flours, and with the latter is not as efficient as maltose with phosphate.

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